Golden Gate Dam Site

The Golden Gate Dam site is in a narrow, V-shaped water gap on Funks Creek about a mile west of Funks Reservoir and 8 miles west of the town of Maxwell in Colusa County (Photo 9). It is in Sec. 9, R4W, T17N on the Sites 7.5-minute USGS topographic quadrangle.

There are two parallel sandstone ridges at this location where a dam could be built. These ridges are a northern extension of the same sandstone ridges found at the Sites Dam site. At least four different dam locations and designs are under consideration. These are a straight dam axis on the upstream ridge, a straight dam axis along the west side of the upstream ridge water gap, a straight axis on the downstream ridge, and a curved alignment along the west side of the downstream ridge. This geologic investigation was performed on the downstream straight alignment. This proposed dam, in conjunction with the Sites Dam and the Sites northern saddle dams, would impound 1.8 million acre-feet of water in Sites Reservoir. The proposed dam would be a 310-foot high embankment structure with a 1,800-foot crest length at an elevation of 540 feet. No spillway is associated with Sites Dam. The only spillway is part of the Golden Gate outlet works just south of the right abutment.

Previous geologic work was performed by USBR in the early 1960s with additional work in the early 1980s. This included geologic mapping at the straight dam axis on the upstream ridge and drilling three vertical drill holes along that proposed axis and an additional vertical hole upstream of the axis. USBR also drilled another vertical hole and trenched two trenches in the channel near DWR's straight downstream axis, and one trench upstream of the upstream axis. The current investigation by DWR's Northern District and Project Geology staff consists of additional geologic mapping, diamond core drilling, auger holes, and seismic refraction surveys.

Dam Site Geology

The site was first mapped by USGS as part of its regional geologic mapping (Calif., Glenn and Colusa Counties 1961). Additional mapping was done by USBR in 1963 as part of its *West Sacramento Canal Unit Report* (DOI-USBR 1964). This mapping was used as the basis for DWR Northern District geologic mapping of the site July through December of 1998. DWR's Division of Engineering assisted with this mapping, and both its mapping and draft report have been incorporated into this report. Foundation rocks are Cretaceous sedimentary rocks of the Cortina and Boxer Formations that are upturned to form a series of north- to northwest-trending homoclinal ridges that dip from 45 to 55 degrees downstream to the east. These interbedded sandstones, siltstones, and mudstones constitute the foundation of the proposed dam. The sandstones and siltstones are more resistant and form ridges in the area that generally have minimal soil cover.

The proposed axis for the dam ties into one of these prominent ridges. The mudstones are generally covered by soil and colluvium and occupy topographic lows.

The mudstones are not exposed in outcrops except in road cuts, streambanks, or from landslide scarps. Minor colluvial soil also mantles the abutments. Quaternary alluvial deposits cover bedrock in the stream channel to depths of about 4 feet. Quaternary terrace deposits also border the channel and have a thickness up to 30 feet. They are composed of silt, sand, gravel, and cobbles, mantled by a clayey soil.

Plates 4 and 5 present the geologic mapping, geologic cross sections, RQD, water pressure tests, and minimum/maximum water levels. Detailed logging and photodocumentation of the drill core is presented in Technical Memorandum A. Details of the water pressure testing are presented in Technical Memorandum B. Details of the groundwater monitoring are presented in Technical Memorandum C.

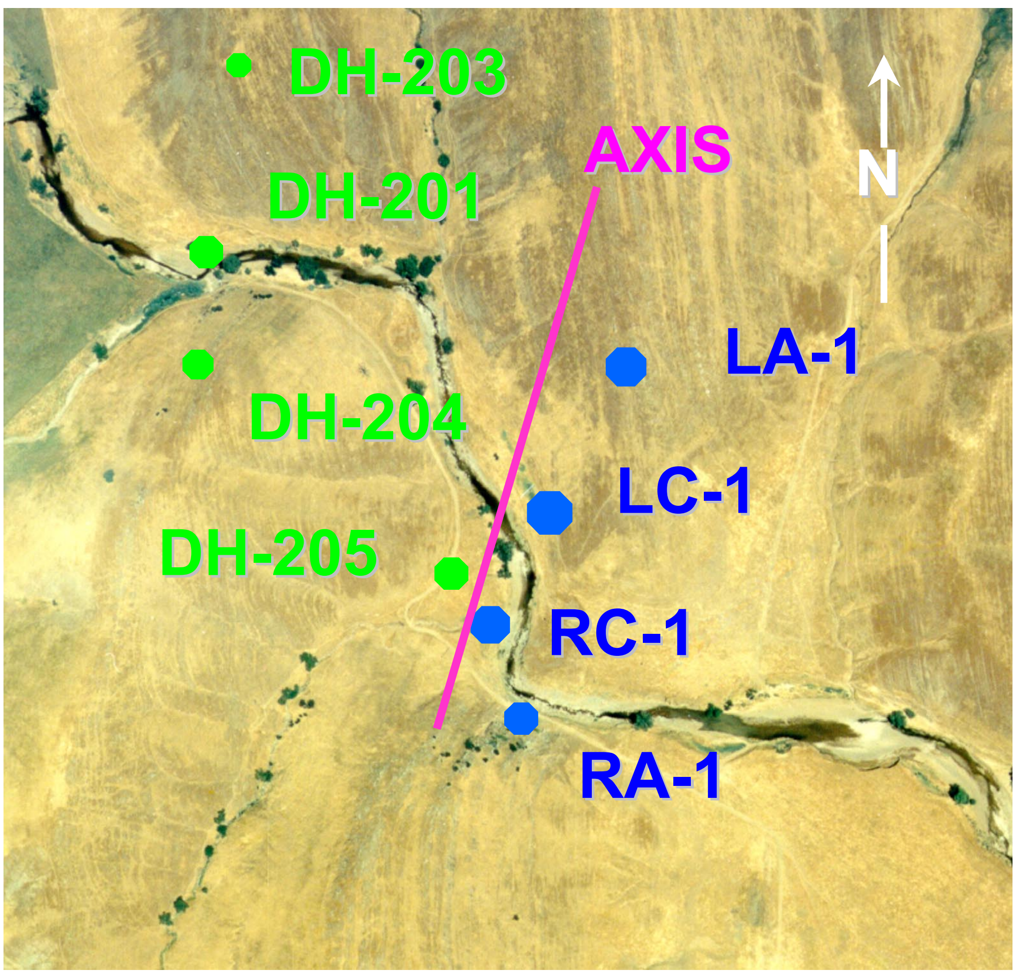

Photo 9. Aerial view of Golden Gate Dam site on Funks Creek with the downstream axis and drill holes

Bedrock Units

The proposed Golden Gate Dam foundations consist of interlayered beds of Upper Cretaceous sandstone, siltstone, and mudstone of the Boxer and Cortina Formations. Sandstone and siltstone comprise about 65 percent of the foundation mainly downstream of the axis, with mudstone comprising the upstream 34 percent of the total footprint of the dam as illustrated on Plate 4, an engineering geology map of the Golden Gate Dam site.

These bedrock units were differentiated into mappable units as follows:

- KCVs - predominantly silty sandstone (70 to 100 percent) of the Venado member of the Cortina Formation with mudstone intervals (0 to 30 percent) up to 5 feet in thickness.

- KCVsm - interbedded mudstones (30 to 70 percent) and silty sandstones (30 to 70 percent) of the Venado member of the Cortina Formation.

- KBm - predominantly mudstone (70 to 100 percent) of the Boxer Formation with silty sandstone intervals (0 to 30 percent) up to 5 feet in thickness.

The sandstone is the most resistant rock type at the site and comprises about 66 percent of the total areal extent of the foundation. Where fresh, it is light to medium olive gray in color, but yellowish brown where weathered. The sand is very fine to medium grained, angular to subangular, and poorly sorted. The matrix is mostly a calcareous clay. Bedding is mostly massive and outcrops in beds ranging from less than a foot to tens of feet in thickness. It contains thin interbeds of siltstone and mudstone that range from laminar up to five feet in thickness. It is intensely to moderately weathered on the surface to a depth of at least 25 feet. It is moderately to well indurated, moderately to slightly fractured, moderately hard to very hard, and strong. Internal structure is well developed where laminar and vague where massive. Fractures are commonly healed with calcite and minor pyrite.

The sandstone also grades transitionally into siltstones. These are olive gray to olive green and light to dark brown when fresh and contain sandstone and mudstone interbeds. The siltstone is moderately to well indurated, moderately hard to hard, strong, and moderately to slightly fractured.

The mudstone is the least resistant rock type in the area, and comprises about 35 percent of the total a real extent of the foundation. It is dark gray to black in color, and tan where weathered. Bedding is laminar with thin sandstone and siltstone interbeds. When exposed in outcrop, it is brittle and slakes rapidly when exposed to air and moisture. It is moderately indurated to friable, moderately hard to weak, and closely fractured.

Unconsolidated Deposits

Unconsolidated deposits at and in the dam foundation consist of Quaternary alluvium, stream terraces, colluvium, and landslides.

Quaternary alluvium (Qal) is in the active stream channel of Funks Creek and consists mainly of lean clay, silt, sand, gravel, cobbles and boulders. It occurs along the edges of the channel and as discontinuous deposits within the channel. It is up to 5 feet in thickness.

Two distinct terraces occur at the Golden Gate Dam site. The first is a low terrace (Qt1) that occurs as discontinuous remnants along the stream course about 5 to 7 feet above the channel. It is generally 4- to 6-feet thick with weak soil development and consists of clayey silt with some minor gravel. The color ranges from dark yellowish brown to very dark grayish brown. Gravel clasts are subangular sandstone. The upper terrace (Qt2) occurs as a broad flat surface with very little relief and occupies the floor of the valley. This terrace is wide spread both above and below the dam site and is 12 to 30 feet thick downstream of the axis. Soil development is greater than on the lower terrace but still moderate. The upper part of this terrace is clayey silt with increasing clay downward. Gravel lenses are observed along the sides of the incised stream channel and encountered in several of the boreholes. In places there is a clay bed at the base of the observable deposit. The upper 2 to 3 feet are dark grayish brown, becoming lighter with depth. These terraces may be correlative with the Lower Modesto Formation as mapped by Helley and Harwood (1985).

Colluvium occurs at the base of the steeper slopes and consists of clayey silt and sand with angular rock fragments. The colluvium ranges to 5 feet in thickness.

Thirty-two areas of potential zones of instability including landslides have been mapped at or near the proposed dam axis. Thirty-one of these have been mapped within the footprint of the dam, and one mapped just outside to southwest. Twenty-four of these zones of instability are small surficial debris and earth flows ranging from about 5 to 75 feet wide. Some may be related to the GG-2 fault that trends diagonally at about N45°E through the foundation for the curved and straight axes.

Five larger debris flows within the footprint range in area from about 7,500 to 75,000 square feet. Large rocks are scattered along the base of the right abutment and in the channel, in an area about 180 feet by 350 feet. These are probably associated with an old quarry operation at the site.

Structure

The primary structural feature at the Golden Gate Dam site is the northerly striking, easterly dipping homoclinal bedding of the Great Valley sequence. Local bedding attitudes mostly strike from N10°W to N10°E and mostly dip from 45 to55 degrees downstream to the east. These are consistent with the regional trend in the Great Valley sequence.

Faults and Folds

USGS mapped the Salt Lake fault and three associated right lateral tear faults at or in the vicinity of the Golden Gate Dam site (Calif., Glenn and Colusa Counties 1961). The northerly trending Salt Lake fault occurs less than a mile to the west. It parallels the axis of the Sites anticline, a major double plunging, and isoclinal anticline just west of Logan Ridge. This anticline and the adjacent Fruto syncline extend northward 40 miles or more. The fault is a high-angle reverse fault with salt-water springs, gas seeps, and sag ponds that occur along the fault trace. The regional trend for the tear faults is from southwest to northeast with a near vertical dip. They are probably associated with the same compressional forces that created the Sites anticline, Fruto syncline, and Salt Lake fault.

GG-1 tear fault trends NE with about 80 feet of apparent right lateral offset. It trends diagonally across the left abutment of USBR upstream dam site, missing the left abutment of the proposed downstream dam site by about 1,400 feet.

GG-2 tear fault trends N45°E with about 650 feet of apparent right-lateral offset (Photo 10). It trends from the southwest across the right abutment of the straight downstream axis, then continues across the channel slightly downstream of the proposed axis, traversing across the downstream portion of the left abutment, and continuing to the northeast an additional 2 miles. Evidence for this fault includes offsets in sandstone outcrops, small surficial landslides on both abutments, and shearing, gouge, and slickensides encountered in the DWR angle drill hole RC-1 from 73 to 99 feet.

USBR excavated several trenches prior to 1981 at the upstream and downstream Golden Gate Dam sites. Two were excavated on the Qt2 terrace at the toe of the left abutment in an attempt to intercept the GG-2 tear fault, but both collapsed. USBR logged the terrace deposits as silty clay.

GG-3 tear fault also trends NE with about 480 feet of apparent right lateral offset. It extends across both main sandstone ridges, about 4,300 feet to the south of the left abutment of the proposed downstream straight axis dam site. It cuts across the proposed intake channel for Golden Gate Dam. The presence of this faulting near the Golden Gate Dam site is a concern and is being further evaluated by the consulting firm of William Lettis and Associates as part of its fault and seismic investigation.

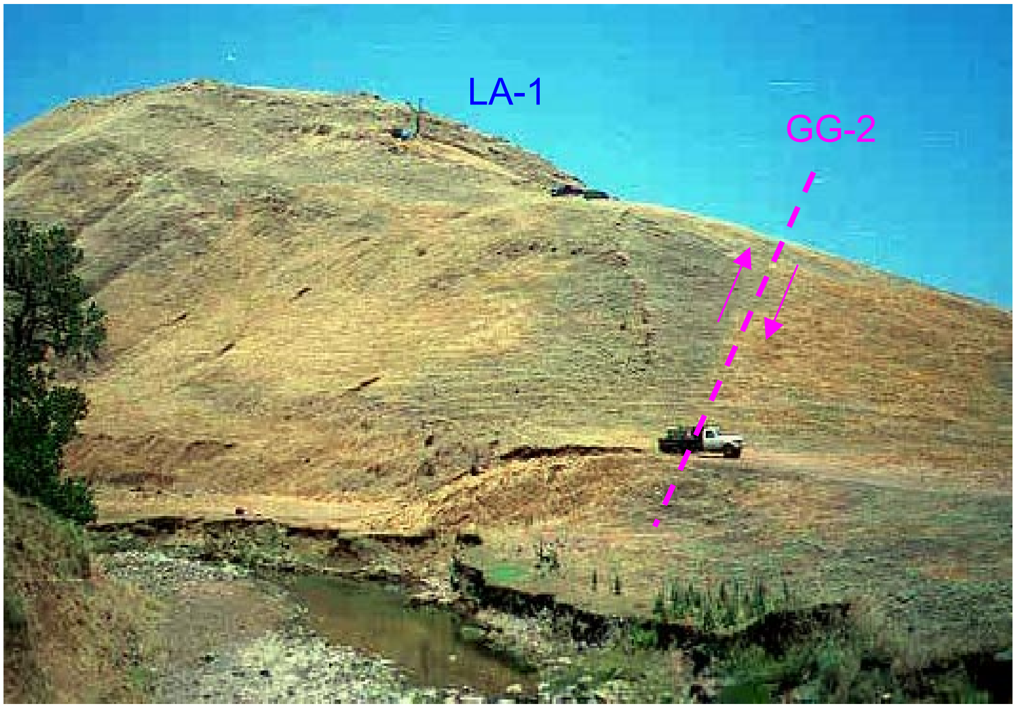

Photo 10. NE view of GG-2 fault on left abutment of Golden Gate Dam site

Several minor lineaments may exist on the left abutment. DWR mapped one as trending from the downstream toe upslope at about N45°W passing just below the dam crest. This minor feature is estimated to have less than a foot of offset. Another minor normal lineament may trend east-west about halfway down the left abutment through a small saddle. This feature is speculative at this time and is based on the topography and numerous small debris flows on the upstream side of the left abutment ridge.

Bedding in the vicinity of the dam site is uniformly homoclinal, trending north-south, and dipping to the east with little folding. Rip-up clasts are common, as is minor bedding plane deformation caused by turbulence during deposition of these sediments. These small-scale features should not present any difficulties with design or construction.

Joints

One joint set trends east-west with a near vertical dip.

Foundation Conditions and Exploration

The rock at the Golden Gate Dam site should provide a good foundation for the proposed dam with minor clearing and moderate stripping. This investigation has verified the existence of at least one fault (GG-2) that is in both abutments of the downstream straight axis. This investigation suggests that the right abutment may contain open fractures and joints that may act as conduits for seepage flow. This is evidenced by some minor springs at the toe of the right abutment that apparently show increased flows associated with high water takes at depth in DWR vertical drill hole RA-1. Table 5 summarizes the foundation conditions.

The site was mapped on a regional scale initially by USGS in 1961, and later by USBR in 1963 and 1980, with additional detailed mapping by DWR's Northern District with assistance from DWR's Division of Engineering. In general, the lithology consists of upturned Upper Cretaceous sedimentary rocks consisting of dominant sandstone, mudstone, and minor conglomerate. The units strike northerly, nearly parallel with the proposed downstream straight axis, and dip downstream 45 to 55 degrees to the east. The foundation bedrock averages about 65 percent sandstone and 35 percent mudstone interbeds under the footprint of the dam (Figure 5 and Plate 4). The relative percentages of sandstone increase markedly in the main ridge, with a 100-foot thick sandstone bed in the Venado member of the Cortina Formation underlying both abutments of the proposed downstream straight axis. There is about 70 percent mudstone in the Boxer Formation upstream of the dam axis with sandstone and siltstone comprising the remaining 30 percent. This unit exhibits more weathering than the sandstone ridge, resulting in gullies that drain north and south into the Funks Creek channel just upstream of the abutments. Weaker mudstone has caused the drainage course of Funks Creek to turn 90 degrees to the south along the base of the left abutment. This may be partially influenced by the right-lateral movement of the GG-2 fault. The channel contains about 18 percent alluvium, 75 percent terrace deposits, and 7 percent landslide deposits.

In 1979-80 USBR drilled and water pressure tested three vertical diamond core holes (DH 201, DH 203, and DH 204) along the proposed straight upstream axis. One hole was drilled to evaluate a pumping plant foundation on a terrace near the downstream straight alignment (DH 205). DWR drilling concentrated on evaluating the foundation conditions and the presence of the GG-2 fault within the dam footprint.

In the spring of 1998 DWR contracted with All-Terrain Drilling to provide drilling and testing services. After completing work at Sites, All-Terrain's CME-850 track mounted rig moved to the Golden Gate Dam site. Four diamond core holes were drilled totaling 836.3 feet, and three auger holes totaling 67.7 feet (Table 6). Three vertical holes were drilled near the dam axis in the channel and on both abutments to evaluate foundation conditions of the Cortina Formation. Another angle hole was drilled to intercept and evaluate rock conditions associated with GG-2 fault in the channel. Three holes were augered through the terrace deposits to bedrock. Water pressure testing was performed on all of the drill holes to determine the permeability of the Cortina Formation in the dam footprint.

TABLE 5 – Sites Reservoir Project, Golden Gate Dam Site Foundation Conditions (total area of Dam Site Footprint = 2,516,100 feet^2)

FEATURE	SURFICIAL/BEDROCK GEOLOGY (by area in feet^2)*	CLEARING ESTIMATES	STRIPPING ESTIMATES	WATER LEVELS	GROUTING ESTIMATES	STRUCTURAL REMARKS
Left Abutment Axis Length = 695feet. Max Footprint Length = 1,470 feet. Min Elev. = 250 feet. Max Elev. = 540 feet. DWR Drill hole = LA-1 (placed 500 feet. north of channel 210 feet. up ridge just east of dam axis) Seismic line = S-6 (placed 465 feet east if where dam axis intersects channel).	Surficial Qls = 67,600 feet^2 (9%) Qc = 686,500 feet^2 (91%) Total Area = 754,100 feet^2 Bedrock KCVs = 285,400 feet^2 (38%) KCVsm = 399,500 feet^2 (53%) KCVm = 69,200 feet^2 (9%) Total Area = 754,100 feet^2 Therefore: Ss = from 319,700 feet^2 (42%) to 585,800 feet^2 (83%) Ms = from 119,800 feet^2 (17%) to 434,500feet^2 (58%)	Light: Scattered grasses interspersed between open sandstone outcrops. A few heavy shrubs in drainage.	The upper 5 feet of soil, colluvium, and intensely weathered rock can be stripped with common methods. An additional 20 feet of moderately weathered rock may need to be excavated.	DWR drill hole LA-1 measured 70 feet in July 1998 but Sept. 1998 to Dec.1999 has remained in the range of 51 to 58 feet.	DWR drill hole LA-1: high grout takes from 7 to 35 feet in a zone of intensely to moderately weathered and abundant fractured sandstone/mudstone. Moderate grout takes between 52 to 62 feet and low grout takes from 72 to 95 feet. The rest of the hole requires little to no grouting.	The NE striking GG-2 fault strikes diagonally across the left abutment in the NE corner of the proposed dam footprint. DWR drill hole LA-1 shows some intense fx from 5 to 13 feet and a shear zone that contains intense fx., gouge and sheared fragments from 125 to 129 feet.
Channel Section Axis Length = 575 feet. Max Footprint Length = 2015 feet. Min Elev. = 235 feet. Max Elev. = 290 feet. USBR Drill holes =DH-201 (placed in channel 100 feet. upstream of dam footprint toe) & DH-205 (placed to the right of channel 35 feet. upstream of dam axis). DWR Drill holes LC-1, RC-1, AUG-4, & AUG-6 are located respectively 100, 40, 1300, & 600 feet. downstream of the dam axis. Of the DWR holes AUG-4 & AUG-6 are the only holes located outside of footprint at this dam site. Seismic lines = S-1, S-2, S-3, S-4 & S-5 (placed in various location from the dam axis to 600 feet. west of where dam axis intersects channel).	Surficial Qls = 50,300 feet^2 (7%) Qal = 128,900 feet^2 (18%) Qt_1 = 55,300 feet^2 (8%) Qt_2 = 474,400 feet^2 (67%) Total Area = 708,900 feet^2 Bedrock KCVs = 324,000 feet^2 (44%) KCVsm = 232,100 feet^2 (31%) KCVm = 181,800 feet^2 (25%) Total Area = 737,900 feet^2 Therefore: Ss = from 296,400 feet^2 (40%) to 541,000 feet^2 (89%) Ms = from 69,600 feet^2 (11%) to 441,000 feet^2 (60%)	Light: Light riparian bordering stream = grasses, oak and cottonwood trees, grasses on terrace deposits	Along dam axis the upper 25 feet of alluvium, terrace deposits, and intensely weathered rock can be stripped with common methods. An additional 7 to 20 feet of moderately weathered rock may need to be excavated. Upstream of dam footprint at USBR hole DH-201 the upper 17 feet of alluvium, channel, and terrace deposits can be stripped with common methods. An additional 4 feet of lightly weathered rock with some intense fracturing may need to be excavated.	USBR DH-205 during drilling in Dec. 1979 measured 25 to 24.5 feet in depth below surface. Then during summer of 1999 depths were measured at 25 feet DH-201 had a depth to water 6 to 2 feet below surface during drilling. DWR drill hole RC-1 varied from 17 to 25 feet in depth from summer of 1998 to winter of 1999. DWR LC-1 has varied 10 to 14 feet from summer of 1998 to winter of 1999.	USBR Drill Hole DH- 201: shows that the entire hole is impervious. No water pressure test was done on DH-205. DWR drill hole RC-1 will require high grouting from 28 to 41 feet possibly due to an intensely to closely fractured zone from 23 to 41 feet. The rest of this hole will require little to no grouting. DWR drill hole LC-1 has high grouting requirements from 19 to 36 feet. but would not be need to be grouted because it would probably be excavated in dam construction. The rest of this hole requires little or no grouting.	The GG-2 fault strikes diagonally across the channel just west of the dam axis. It does not show up in the terrace deposits. USBR drill hole DH-201 intercepts shears parallel to bedding from 19 to 20 feet and at 29 feet. that contain fragments, slicks and gouge. There is also a zone of intensely and very intensely fracture rock with slicks at 61 to 73 feet. DH-205 has a zone of intensely fractured rock from 25 to 35 feet. DWR drill hole LC-1 shows Intense to closely fx from 15 to 22 feet and intense fx at 42 to 43 feet. and 85 to 86 feet. DWR drill hole RC-1 shows fx. from 32 to 124 feet. with zones of intense fx at 32 to 58 feet, 73 to 99 feet, and 107 to 124 feet. some slicks and gouge between 73 to 99 feet.
Right Abutment Axis Length = 565 feet. Max Footprint Length = 2195 feet. Min Elev. = 255 feet. Max Elev. = 540 feet. DWR Drill hole = RA-1 (placed 865 feet. south of channel 225 feet. up ridge just east of dam axis) No seismic done.	Surficial Qls = 60,600 feet^2 (6%) Qc = 963,500 feet^2 (94%) Total Area = 1,024,100 feet^2 Bedrock KCVs = 588,700 feet^2 (57%) KCVsm = 364,500 feet^2 (36%) KCVm = 70,900 feet^2 (7%) Total Area = 1,024,100 feet^2 Therefore: Ss = from 521,400 feet^2 (51%) to 865,100 feet^2 (89%) Ms = from 109,400 feet^2 (11%) to 502,700 feet^2 (49%)	Light: Scattered grasses interspersed between open sandstone outcrops, some very sparse oak trees present.	The upper 5 feet of soil, colluvium, and intensely weathered rock can be stripped with common methods. An additional 20 feet of moderately weathered rock may need to be excavated.	DWR drill hole RA-1 varied from 53 feet to 90 feet below surface from summer of 1998 to Dec. of 1999.	DWR drill hole RA-1 will require high grout takes at 15 to 46 feet, 56 to 76 feet, 94 to 106 feet, and 214 to 246 feet in fractured Ms/sSs. Rest of the hole requires low to no grouting.	The NE striking GG-2 fault strikes diagonally across the right abutment in the SW corner of the of the proposed dam footprint. DWR drill hole RA-1 shows intense fracturing from 9 to 14 feet.

Ss = Sandstone Ms = Mudstone Cgl = Conglomerate Qal = Quaternary Alluvium Qc = Quaternary Colluvium Qt_1 = Quaternary Terrace (lower) Qt_2 = Quaternary Terrace (upper) Fx = fracturing
*** Total Foundation Area of Damsite Footprint = 2,516,100 feet^2, therefore total Ss = from 1,137,500 feet^2 (45%) to 1,991,900 feet^2 (87%); total Ms = from 298,800 feet^2 (13%) to 1,378,600 feet^2 (55%)**

FIGURE 5: Sites Reservoir Project, Golden Gate Dam Site Surficial and Bedrock Lithology By Percentage

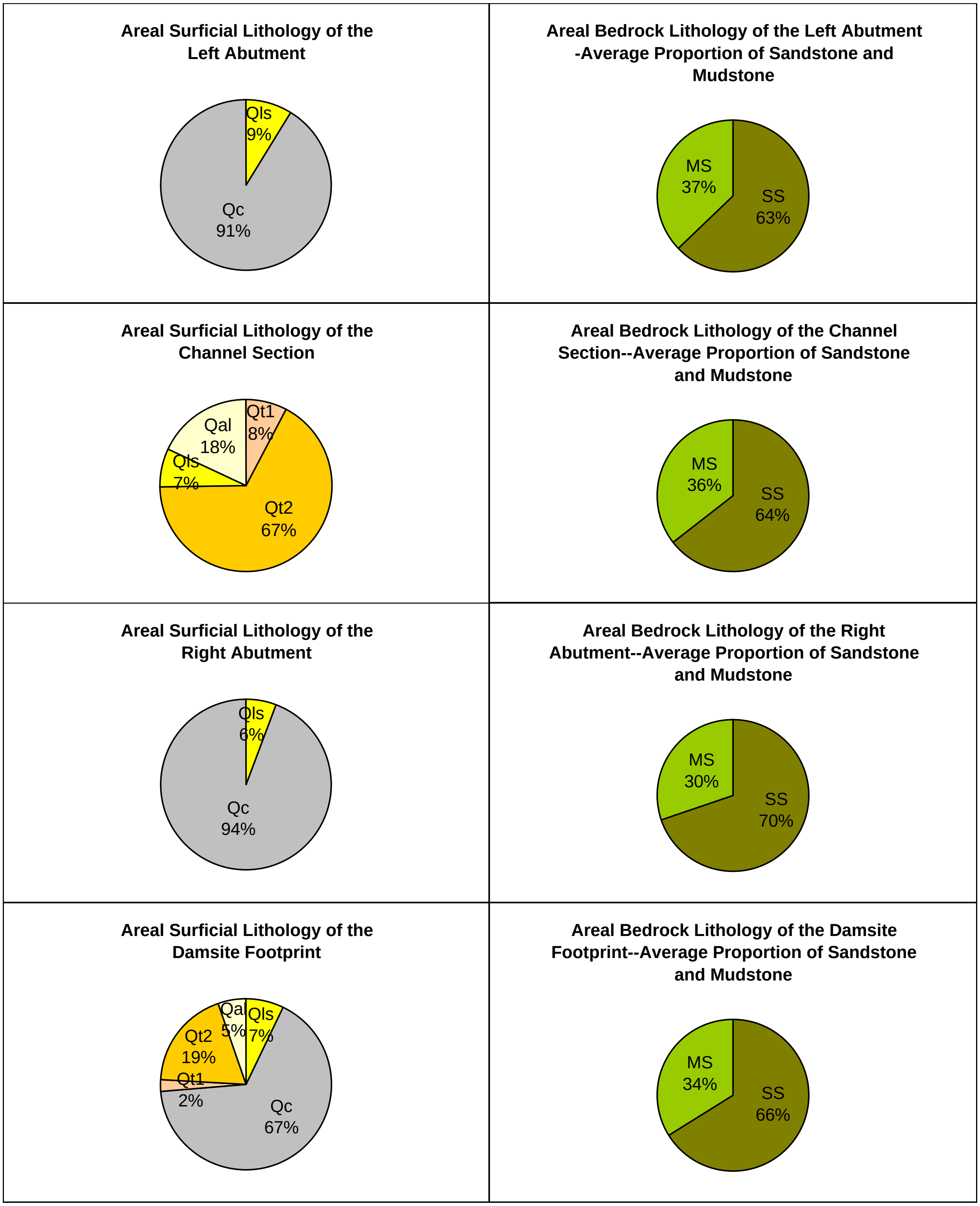

Table 6. DWR drilling footage of Golden Gate Dam site

Drill site	Drill hole	Date started	Date completed	Drilled footage (feet)
Golden Gate Dam Site	RC-1	Jun 22, 1998	Jun 28, 1998	134.6
	LC-1	Jun 29, 1998	Jul 06, 1998	203.7
	LA-1	Jul 08, 1998	Jul 15, 1998	248.8
	RA-1	Jul 21, 1998	Jul 24, 1998	249.2
	Total HQ diamond drill footage			836.3
	AUG-4	Jun 26, 1998	Jun 26, 1998	21.0
	AUG-5	Jun 22, 1998	Jun 22, 1998	18.7
	AUG-6	Jun 22, 1998	Jun 22, 1998	28.0
	Total auger footage			67.7
	TOTAL footage			904.0

LA = Left abutment drill hole
LC = Left channel drill hole
RC = Right channel drill hole
RA = right abutment drill hole
DHPP = Drill hole power plant
DHS = Drill hole spillway
DHT = Drill hole tunnel
SSD = Sites saddle dams
AUG = Auger hole

Vertical drill hole LA-1 was drilled to a depth of 248.8 feet to evaluate the sandstone and mudstone underlying the left abutment (Photo 11). No core was recovered from 0.0 to 4.6 feet. The sandstone was generally hard. From 4.6 to 12.6 feet, it drilled through 70 percent mudstone with 30 percent sandstone interbeds. From 12.6 to 47.2 feet, it intersected 100 percent sandstone. From 47.2 to 157.4 feet, the hole drilled through 80 percent mudstone with 20 percent sandstone interbeds. From 157.4 to 248.8 feet, the hole intersected 85 percent sandstone with 15 percent mudstone interbeds. From 125.1 to 128.8 feet, a bedding plane shear with associated gouge and slickensides was encountered. Some minor shears were encountered at 166.0, 197.4, 245.0, and 246.6 feet.

Vertical drill hole LC-1 was drilled to a depth of 203.7 feet to evaluate the sandstone underlying the channel. The initial 15.0 feet of the hole encountered clayey terrace deposits (Qt). From 15.0 to 203.7 feet, the hole encountered mostly (85 percent) sandstone with lesser (15 percent) mudstone interbeds. The rock was intensely- to closely-fractured to a depth of 22 feet and moderately to slightly fractured below 22 feet. Intense fracturing with minor slickensides also exists from 42.4 to 42.8 feet, and from 85.2 to 85.7 feet.

Photo 11. CME-850 drill rig at Golden Gate Dam site drill hole LA-1

Angle hole RC-1 was drilled at 45 degrees to a depth of 134.6 feet to intercept the GG-2 fault as mapped and to evaluate associated permeability in the foundation (Photo 12). It encountered sandy clay terrace deposits in the initial 32.4 feet. From 32.4 to 123.9 feet, the hole encountered intense fracturing, gouge, and slickensides. It intersected 75 percent mudstone with 25 percent sandstone interbeds. The hole drilled through 100 percent sandstone from 123.9 to 134.6 feet. A 26.4-foot zone of intense fracturing, gouge, and slickenslides that probably represents the GG-2 fault was encountered from 73.0 to 99.4 feet (Photo 13). Another zone of intense fracturing that may be related was encountered from 32.4 to 58.1 feet.

Vertical drill hole RA-1 was drilled to a depth of 249.2 feet to evaluate the Cortina sandstone and mudstone underlying the right abutment. It drilled through about 5 feet of sandy clay colluvium (Qc). The hole drilled through up to 90 percent sandstone with 10 percent mudstone interbeds. Some intense fracturing probably associated with near surface weathering was encountered from 5.0 to 9.2 feet, but moderately to slightly fractured to 30 feet. Only a few minor shears were encountered. Three auger holes were augered through terrace deposits downstream of the axis to determine depths to bedrock and to obtain samples for evaluating construction materials (Photo 14). AUG-4 was placed 1,300 feet downstream of the axis and augered through 21.0 feet of terrace deposits to bedrock. AUG-5 was placed about 2,100 feet downstream of the axis and augered through 18.7 feet of terrace deposits to bedrock. AUG-6 was placed 600 feet downstream of the axis and augered through 28.0 feet of terrace deposits to bedrock. After completion of drilling at Golden Gate, the drill rig was moved north to explore the Hunters Dam site as part of the Colusa Reservoir Project.

Photo 12. CME-850 drill rig at Golden Gate Dam site angle drill hole RC

Seismic Refraction Surveys and Rippability

Seven seismic refraction surveys totaling 1,000 feet in length were performed in January of 1998. Six of these were done in the channel on the upper and lower terraces. Depths to bedrock ranged from 5.3 to 9.5 feet for the lower terrace, and from 17.1 to 19.9 feet for the upper terrace. An additional survey on the left abutment showed that the colluvial overburden and weathered bedrock depth was about 11 feet.

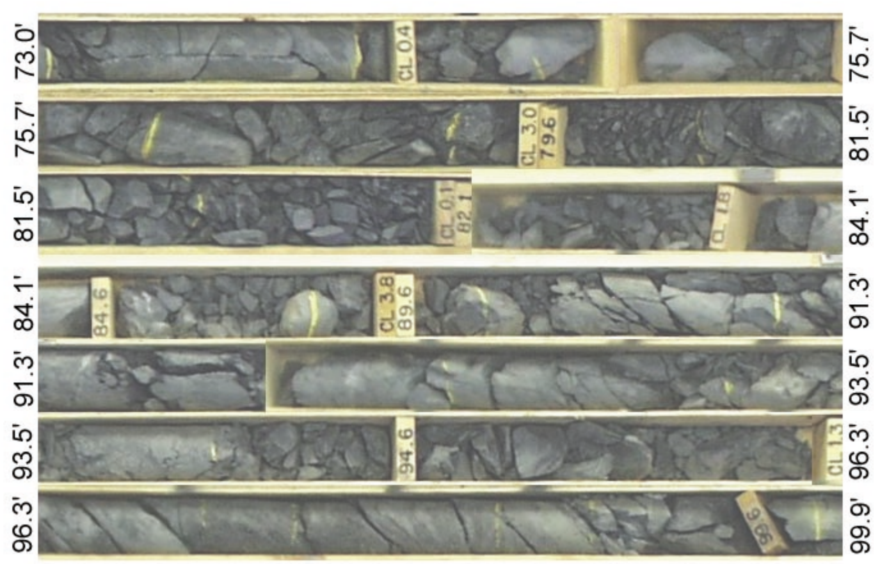

Photo 13. Fault GG-2 from 73.0 feet to 99.4 feet in Golden Gate Dam drill hole RC-1

The seismic velocities for the lower terrace deposits ranged from 664 to 1,527 feet per second with a median of 1,095 feet per second. Seismic velocities for the upper terrace deposits averaged 1,149 feet per second. Both of these deposits should be easily rippable. Velocities for the underlying bedrock ranged from 3,203 to 13,699 feet per second with a median of 7,429 feet per second. This meant that the bedrock ranged from rippable (mudstone) to non-rippable (sandstone).

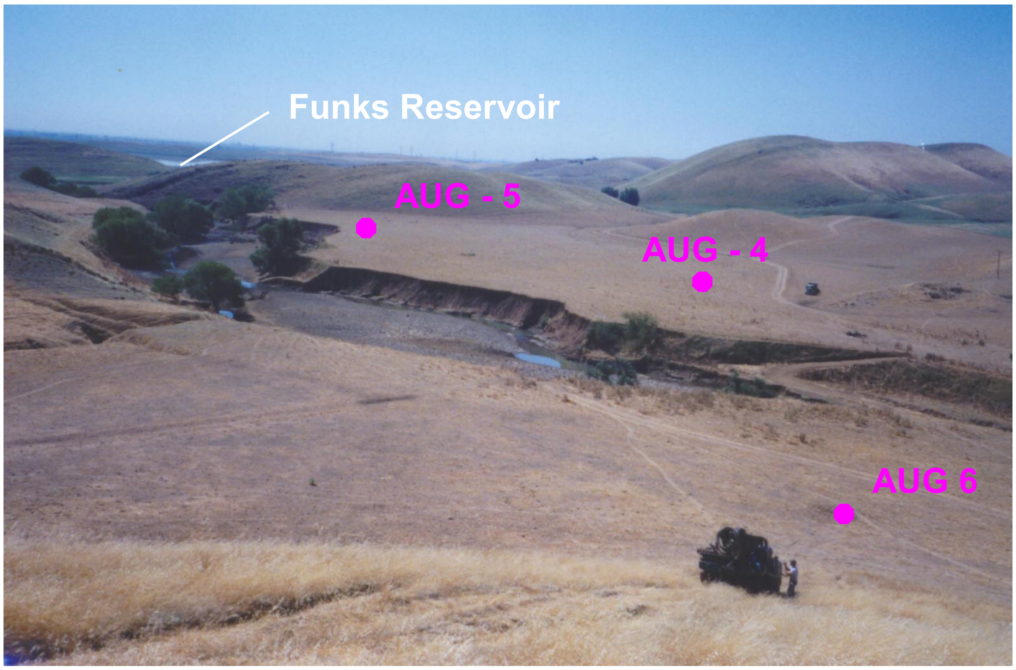

Photo 14. Auger holes on terraces downstream of Golden Gate Dam site

Rock Strength

Logging of the core indicates that the rock strength of the sandstone ranges from very poor to excellent. Both USBR and DWR used rock quality designation (RQD) in logging of the core (see Tables 7, 8, 9, and Plates 4 and 5). This parameter is used as an indicator of the competence of rock. In general, RQD values indicate that the left abutment along the axis has excellent rock quality deeper than 21 feet except for poor rock from 124 to 129 feet. Rock quality in the channel upstream of the axis is fair to 20 to 194 feet. The rock quality in the channel is fair from 22 to 49 feet, then excellent to the bottom of hole at 204 feet except for poor to very poor intervals from 86 to 98 feet, and from 189 to 194 feet. Also, the rock quality in the channel in the vicinity of the GG-2 fault crossing is generally good from 27 to 37 feet, then poor to 52 feet, then very poor to bottom of hole at 67 feet. The right abutment along the axis has fair rock quality to 65 feet, then excellent rock quality to 249 feet.

Table 7. Golden Gate Dam site-seismic refraction data

First Horizon - Terrace Deposits							
Date	Line	Length (Feet)	Velocity 1 Forward (ft/sec)	Velocity 1 Reverse (ft/sec)	Composition	Rippability	Average Thickness (feet)
1/22/98	SL-1	150	800	500	Alluvium	Rippable	18
1/22/98	SL-2a	80	800	800	Alluvium	Rippable	9
1/22/98	SL-2b	80	700	700	Alluvium	Rippable	10
1/23/98	SL-2c	80	900	1100	Alluvium	Rippable	8
1/30/98	SL-2d	80	1400	1400	Alluvium	Rippable	17
1/23/98	SL-3a	80	*	*	Alluvium	*	*
1/23/98	SL-3b	80	1100	1100	Alluvium	Rippable	7
1/30/98	SL-4a	60	1400	1400	Alluvium	Rippable	7
1/30/98	SL-4b	60	1500	1500	Alluvium	Rippable	8
1/30/98	SL-5a	60	1400	1400	Alluvium	Rippable	6
1/30/98	SL-5b	60	1300	1400	Alluvium	Rippable	5
1/30/98	SL-6	50	1500	1500	Alluvium	Rippable	12

Second Horizon – Interbedded Sandstone and Shale						
Date	Line	Length (Feet)	Velocity 2 Forward (ft/sec)	Velocity 2 Reverse (ft/sec)	Composition	Rippability
1/22/98	SL-1	150	9500	5400	Sandstone/Shale	Marginal
1/22/98	SL-2a	80	5700	5400	Sandstone/Shale	Rippable
1/22/98	SL-2b	80	11700	13700	Sandstone/Shale	Non-Rip
1/23/98	SL-2c	80	5400	3200	Sandstone/Shale	Rippable
1/30/98	SL-2d	80	8800	8400	Sandstone/Shale	Marginal
1/23/98	SL-3a	80			Sandstone/Shale	Rippable
1/23/98	SL-3b	80	8300	4500	Sandstone/Shale	Rippable
1/30/98	SL-4a	60	3600	10000	Sandstone/Shale	Marginal
1/30/98	SL-4b	60	5900	5000	Sandstone/Shale	Rippable
1/30/98	SL-5a	60	5000	5900	Sandstone/Shale	Rippable
1/30/98	SL-5b	60	10400	5100	Sandstone/Shale	Marginal
1/30/98	SL-6	50	11100	12500	Sandstone/Shale	Non-Rip
* Data for seismic line 3A is not shown. It yielded poor results, probably due to operator error in use of the seismic equipment.						

Table 8. Rock quality designation in DWR drill holes at Golden Gate Dam site (downstream axis)

Agency	Drill Hole	Vertical Depth (ft)	Min. RQD*	Max. RQD*	Avg. RQD*	Description
DWR	LC-1	22 49	52	92	69	Fair
DWR	LC-1	49 86	86	100	96	Excellent
DWR	LC-1	86 98	0	62	21	Very Poor
DWR	LC-1	98 189	94	100	100	Excellent
DWR	LC-1	189 194	0	90	38	Poor
DWR	LC-1	194 204	100	100	100	Excellent
DWR	RC-1	38 52	23	100	87	Good
DWR	RC-1	52 74	0	0	0	Very Poor
DWR	RC-1	74 95	0	100	41	Poor
DWR	LA-1	21 124	60	100	91	Excellent
DWR	LA-1	124 129	36	36	36	Poor
DWR	LA-1	129 248	82	100	98	Excellent
DWR	RA-1	26 65	46	100	71	Fair
DWR	RA-1	65 249	76	100	97	Excellent

*Rock quality designation (RQD) is developed by summing the total length as measured along the centerline of the drill core recovered in each run, but only those pieces of core which are at least 4 inches in length are counted that are "hard and sound." The sum is then represented as a percentage over the length of the run.

Several 1-foot samples of sandstone and mudstone were taken for testing by Bryte Laboratory in 1998. A sample from 27.8 to 28.8 feet in drill hole LA-1 had a specific gravity of 2.51, a 3.7 percent loss, and an unconfined compressive strength (UCS) strength ranging from 4,620 psi when tested wet to 11,272 psi when tested dry. A sample from drill hole LC-1 from 35.6 to 36.6 feet had a specific gravity of 2.66, a 1.5 percent loss, and a UCS strength ranging from 4,620 psi when tested wet to 16,852 psi when tested dry. A sample of weathered mudstone from this drill hole from 23.2 to 24.2 feet had a UCS of 1,175 psi when tested dry. Another fresh mudstone sample from 199.5 to 201.5 feet had a dry UCS of 5,395 psi. A weathered sandstone sample from drill hole RA-1 from 16.2 to 17.2 feet had a specific gravity of 2.41, a 5.4 percent loss, and a dry UCS of 7,285 psi. Two fresh sandstone samples were taken from 51.0 to 52.0 feet and from 53.4 to 54.4 feet. When tested wet, they averaged a specific gravity of 2.50, a 3.5 percent loss, and a UCS of 7,225 psi. When tested dry, they averaged a specific gravity of 2.48, a 3.5 percent loss, and a UCS of 13,100 psi.

Table 9. Rock quality designation in USBR drill holes at Golden Gate Dam site (upstream axis)

Agency	Drill Hole	Vertical Depth (ft)	Min. RQD*	Max. RQD*	Avg. RQD*	Description
USBR	DH-201	21–59	27	100	80	Good
USBR	DH-201	59–79	7	63	35	Poor
USBR	DH-201	79–93	80	96	88	Good
USBR	DH-203	26–49	45	100	68	Fair
USBR	DH-203	49–120	29	100	89	Good
USBR	DH-203	120–169	0	100	27	Poor
USBR	DH-203	169–195	70	100	87	Good
USBR	DH-204	22–160	76	100	97	Excellent
USBR	DH-205	35–109	82	100	95	Excellent

Water Pressure Testing and Grouting

Based on the drill holes, the abutments at the Golden Gate Dam site will have significantly higher grouting requirements than will the channel holes, due to the nature of the weathering and fracturing of the sandstone bedrock encountered. Average permeability of the abutments is relatively high at 0.29 feet per day, with Lugeon values averaging 26 for RA-1 and 36 for LA-1.

The channel holes are both composed of mainly mudstone, with some sandstone interbedding. Average permeability is 0.09 feet per day in LC-1 and 0.18 feet per day in RC-1. Average Lugeon values are 7 and 13, respectively. Grouting in these holes will focus on a 15-foot wide zone encountered near the top of each channel hole.

Water tests in left abutment drill hole LA-1 showed water takes of 10.8, 29.2, and 20.8 gallons per minute at depth intervals of 7 to 20 feet, 12 to 25 feet, and 22 to 35 feet, respectively. These losses are associated with weathered and fractured near surface rock conditions. Water losses were relatively low below a depth of about 35 feet. One exception was the test conducted between the depths of about 130 and 145 feet where a loss of about 10.2 gpm was attained. A shear zone is present between the depths of 125 and 129 feet. While the water loss was associated with the test immediately below the shear zone, it may be associated with fractured rock on the footwall of the shear zone.

Water tests in right abutment drill hole RA-1 showed water losses ranging from 3 to 26.6 gpm between the depths of 15 and 75 feet. While some water takes can be associated with weathered and fractured rock to a depth of about 40 feet, the high take of 11.4 gpm from 65 to 75 feet appears high for the quality of rock recovered from drilling. The rock is intensely to closely fractured near 55 feet, 58 feet, and 63 to 65 feet. The drill hole at depth showed numerous water tests with losses exceeding 10 gpm. The maximum loss of 29.4 gpm between 95 and 105 feet may be due in part to a pump leak during the test. Two tests showed losses of 16 and 14.4 gpm at depths of about 215 to 225 feet and 225 to 235 feet, respectively.

Two drill holes, RC-1 and LC-1, were drilled in the channel. Angle drill hole RC-1 was drilled at 45 degrees subparallel to bedding, primarily to intercept the GG-2 fault zone in fresh rock at depth. Water tests in this hole showed losses of 13.5 gpm at angle depths from 40 to 53 feet, and 10 gpm from 45 to 58 feet. There was minimal takes of 0.5 to 1.2 gpm below 58 feet, including the GG-2 fault zone from 73 to 99 feet. Drill hole LC-1 water tests showed high takes of 12.1 and 9.1 gpm at vertical depths of 19 to 32 feet and 23 to 36 feet, respectively. These losses appear to correlate with weathered and fractured rock. Below a depth of 36 feet, the rock is tight with minimal water losses.

Preliminary analysis indicates that high water takes are apparent in the weathered and fractured rock to a depth of about 50 feet. The foundation rock below a depth of about 50 feet is mostly tight with some exceptions (as described above). The construction of a two-line grout curtain with 200-foot deep holes at opposing angles will reduce the likelihood for large ungrouted "windows" to be left in the foundation and provide a positive barrier against seepage beneath the dam. Dam design specifications should provide for construction of a grout cap in the foundation, especially where strongly fractured, jointed, or sheared rocks are exposed at the surface. Overall, grout takes should be low.

Faults/shears and open fractures uncovered in the foundation may require some cleaning and excavation of weakened and sheared rock before placing embankment foundation. These discontinuities could be potential seepage paths through the foundation and will undoubtedly require grouting. Therefore, a minimal amount of blanket grouting should be considered to seal near-surface fractures and joints.

Water Levels

Piezometers were installed in Golden Gate drill holes LA-1, LC-1, RC-1, RA-1, and auger holes AUG-4, AUG-5, and AUG-6. Water levels have been monitored since summer 1998. The water level in the channel was roughly 11 feet below the surface after drilling in summer 1998. Then it dropped another 2 feet during fall 1998 before rising to 10 feet during winter 1999. Since then it has gradually dropped to 13 feet below when measured last fall. The left abutment water level was at about 38 feet below surface just after drilling in summer 1998, then rose to about 20 feet later in fall 1998. This level has held fairly steady ever since, gradually dropping 2 feet to its current level 22 feet below surface. The right abutment water level has followed a completely different pattern. It dropped from a high just after drilling in July 1998 when it was about 2 feet below surface, to a low of about 24 feet in April 1999. It then rose to 12 feet in July 1999, then to about 11 feet in September. The volumes of water pumped into the drill hole during water pressure testing may skew the original measurements. The water level below the right terrace bordering Funks Creek at the dam axis was 25.7 feet deep when measured in USBR DH-205 in September 1999. Auger holes AUG-4 and AUG-5 have measured dry since installed. AUG-6 has ranged from 19.8 feet to 28.2 feet below ground surface.

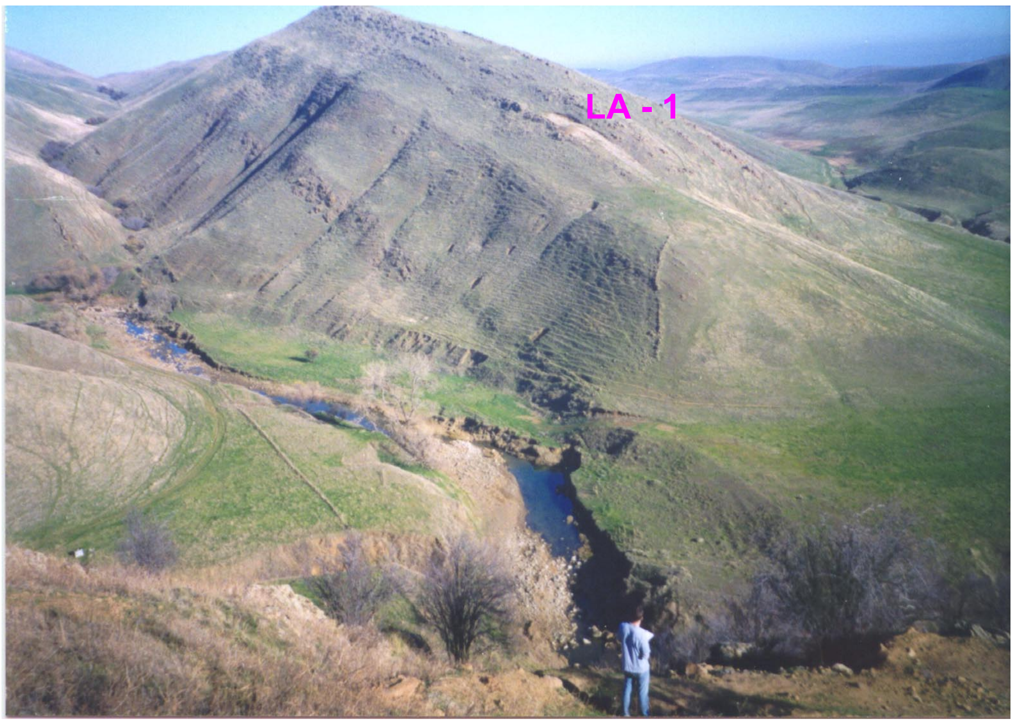

Photo 15. View looking north at Golden Gate left abutment and Funks Creek

Clearing and Stripping

Left Abutment

The left abutment is moderately steep with an average slope of about 1:1 (Photo 15). Unconsolidated deposits on this abutment consist of about 90 percent colluvial soil and 10 percent landslide deposits. It is underlain by about 65 percent sandstone and siltstone, and about 35 percent mudstone. The sandstones form topographic highs often protruding above the surrounding ground surface and the mudstones are commonly associated with topographic lows. These beds strike nearly north-south and dip about 50 degrees toward the east. Most joint fractures strike nearly east-west with a dip between 50 degrees south to 70 degrees north. Vegetation is light on the left abutment, consisting entirely of grasses except for a few heavier shrubs in the south-draining gully. Foundation preparation should include the removal of at least 12 feet of soil, colluvium, and intensely weathered bedrock using common methods, with another 20 feet of moderately weathered

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bedrock that may need to be excavated. The material removed from the stripping probably can be used as random fill.

Channel

The Funks Creek channel varies from 150 to 600 feet in width, and is about 400 feet wide where it crosses the axis (Photo 16). Alluvial cover is moderate with stream channel deposits 5 to 8 feet thick and bordering terrace deposits up to 28 feet thick. Alluvium consists of sand and gravel with some sandy clay, cobbles, and boulders. Some more resistant sandstone outcrops in Funks Creek. Surface water flows occur in Funks Creek year-round but are generally low, so dewatering or diversion should be minimal. The channel has a fairly light and narrow riparian zone, consisting of scattered pockets of grasses, cottonwoods, and oak trees. These are somewhat thicker at the dam axis.

Photo 16. Downstream view of Funks Creek channel of Golden Gate Dam site

Foundation preparation should include the removal of up to 22 feet of alluvium, terrace deposits, minor landslide deposits, and intensely weathered bedrock using common methods. Another 2 to 10 feet of underlying moderately weathered bedrock may have to be excavated. A cutoff trench will probably be required below the core embankment. The excavated material can be used for random fill.

Right Abutment

The right abutment is moderately steep with an average slope of about 1:1 (Photo 17). It is steeper at the toe where an old quarrying operation excavated and steepened the slope by blasting and removal of sandstone. Unconsolidated deposits on this abutment consist of about 95 percent colluvial soil and 5 percent landslide deposits overlie the right abutment. About 70 percent sandstone and siltstone, with about 30 percent mudstone interbeds underlie the abutment. These beds strike nearly north south and dip about 50 degrees downstream toward the east. Most joint fractures strike nearly east west with a dip between 70 degrees south to 70 degrees north. Vegetation is light on the right abutment, consisting primarily of scattered grasses and very sparse oak trees scattered between outcrops along the ridge.

Photo 17 . Southern view of right abutment of Golden Gate Dam site

Foundation preparation should include removal of at least 5 feet of soil and colluvium, and intensely weathered bedrock using common methods, with another 20 feet of moderately weathered bedrock that may have to be excavated. The material removed from the foundation stripping probably can be used as random fill. An average stripping estimate is about 14 feet for the embankment and an additional 16 feet for the cutoff trench. A spring is located at the lower portion of the right abutment. An increase in the flow of water from the spring was observed while water pressure testing DWR drill hole RA-1 on the right abutment. This direct correlation indicates that there are open fractures in the abutment that would act as conduits for seepage. One possibility is that blasting from the quarry operation has widened existing joints and/or fractures.

Conclusions and Recommendations

The rock units should be adequate for the proposed foundation. Faults will require special attention during stripping and grouting.

- High losses during water pressure testing of the right abutment and reactivation of a spring at the base of this slope suggest that open fractures and joints will require sealing and grouting. Water is probably following these open joint sets down gradient to the base of the slope. This needs to be further analyzed.

- Multiple dam alignments are under consideration at report preparation. Currently the most favorable alignment is the downstream curved alignment. Further exploration of this alignment is being prepared and requested by California Department of Water Resources, Division of Engineering, Civil Engineering Branch.

- The possibility that a minor high-angle normal lineament exists on the left abutment should not be ruled out at this time. It could be explored via an angle drill hole oriented roughly north to intercept the possible discontinuity, or by trenching with a hydraulic excavator.